Final Report, 8 September 2012

3 kW PV Technical Due Diligence Report

Zincsolar Pty. Ltd., ABN 34 159 928 408

Undertaken by Murdoch University on behalf of the Client

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Report Brief and Introduction

This report assesses the technical performance by simulation of:

The AC electricity generated from a 96.2% efficient SG 3KTL-31, 3.30 kW_p inverter converting DC electricity generated by a 3.0 kW_p photovoltaic (PV) array comprised of 12 x 250 W_p YL250P-29b polycrystalline modules (See Fig. 1 for module qualifications and certifications). There were 169 simulations for both Perth and Mandurah undertaken at specified array orientations. The total 338 system simulations generated data that indicated the technical performance that unobstructed PV-inverter systems would generate in one year (kWh/year) at each array orientation.

1. Simulation software, system design, and assumptions

The RETScreen, version 4 database was used to incorporate suitable meteorological data into the simulations. The simulations were performed using HOMER version 2.68 beta, released by the National Renewable Energy Laboratory (NREL) on 24 July 2009. HOMER is a distributed power and micro-power optimisation model that simulates the operation of renewable energy-based systems by making energy balance calculations for each simulation interval throughout an entire year[1]. Within the simulations undertaken in this analysis, HOMER calculated the flow of energy to and from the PV array and inverter, and performed energy balance calculations under the specified conditions. (Note that HOMER nomenclature uses the word 'converter' to describe the inverter).

A 10 minute simulation interval was chosen to provide sufficient resolution to the generation outputs. In contrast to more common applications of HOMER, this analysis simply simulates the technical performance of one selected PV-inverter system for various PV array orientations. The PV array orientations selected for analysis were intervals of 2.5 degrees between 17 degrees and 47 degrees relative to horizontal, and azimuth intervals of 15 degrees between 90 to 180 through to 270 degrees West of South. (Simply put, tilting the PV array up and down at various intervals between 15 degrees each side of 32 degrees, as per convention of the location latitude angle, and pointing the array at intermediates between due West, through North, to due East). Two nearby locations were chosen for a comparative analysis: Perth; and Mandurah, both of which are connected to the South West Interconnect System (SWIS) with a standard metropolitan supply of a 240 V, 63 A single phase distribution line. The analysis solely focussed on the electricity produced from the PV-inverter system, and excluded any influence of domestic electricity consumption, or exporting electricity to the SWIS.

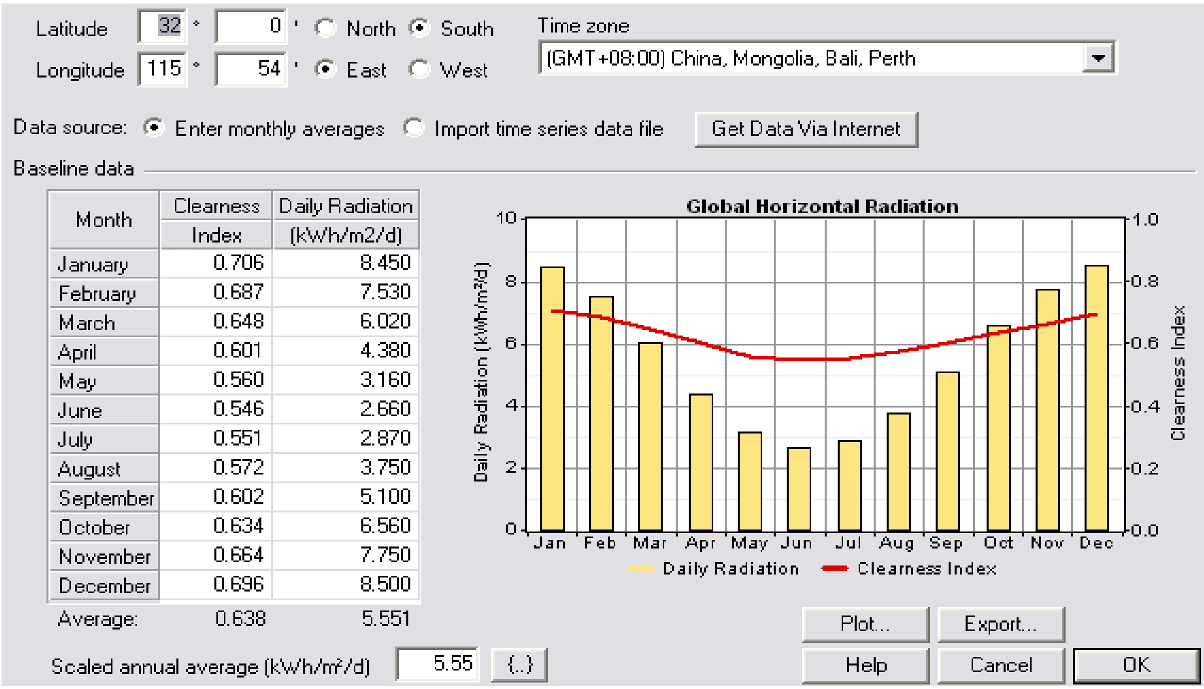
The generic DC-AC inverter conversion efficiency used in all system simulations were based on technical specifications from a SG 3KTL-31, (3.30 kW_p max DC power) with a simplified fixed linear efficiency of 96.2%. All PV technology simulations assumed a very conservative derating factor of 85%, ground reflectance of 20%, and zero shading from obstacles. The PV simulations only included fixed, non-tracking arrays. All (338) system simulations used a P_{MPP} of -0.45%/°C, a NOCT of 46°C, and an efficiency at STC of 15.3%. The use of monthly average temperature data was used as a simplification of the actual environmental conditions. It was assumed that the conservative derating assumptions will more than cater for the additional losses due to higher than average temperatures during actual operation.

Authors note: The accuracy of the PV-inverter system simulation results depend primarily on the accuracy of the input meteorological data and simulation assumptions. The high precision of the simulation outputs should not be misinterpreted as a high level of actual output certainty, as many assumptions underpin appropriateness and accuracy for each unique location and site. The simulation results should only be used as a guide on the understanding that actual system performance results will vary depending on site conditions. An uncertainty assessment of the simulations and input data (primarily meteorological data) has not been undertaken by a third party for this analysis. Nonetheless, much software verification has been undertaken for both the HOMER and RETScreen software packages, and both NASA and BOM have data quality assurance procedures.

Fig. 1: System PV module qualifications and certificates.

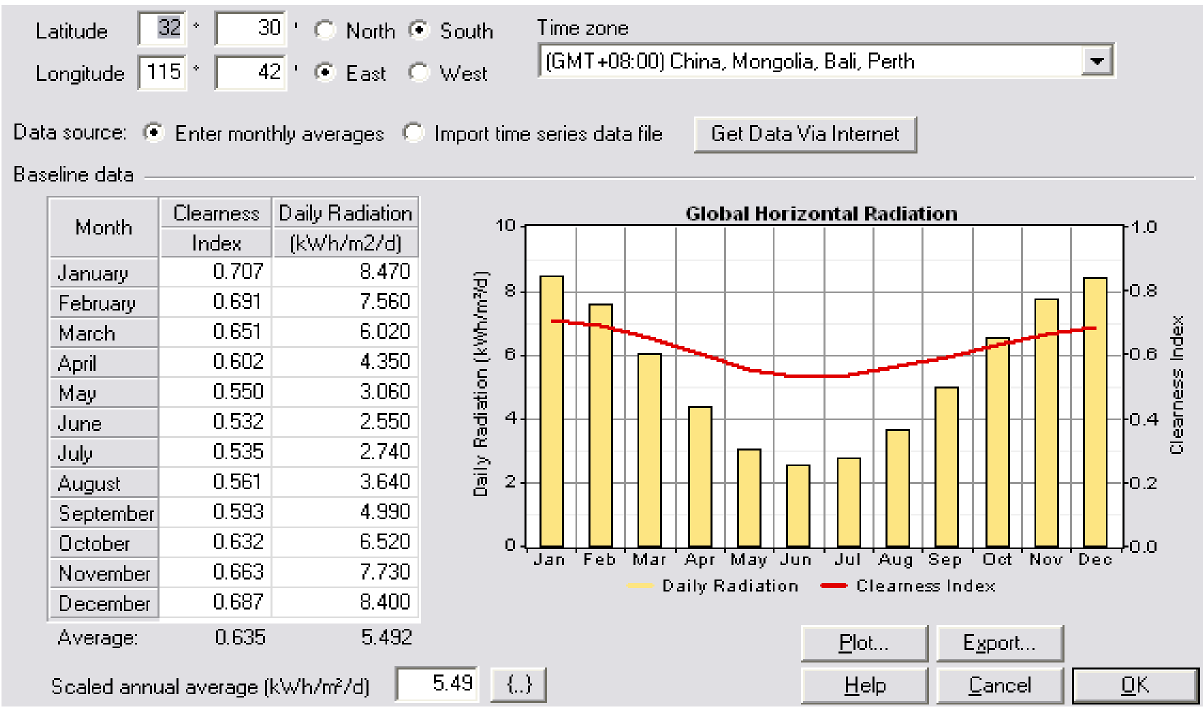
2. Simulation Input Meteorological Data

The daily solar radiation on a horizontal plane and air temperature input data used in the simulations were derived from two Bureau of Meteorology (BOM) stations: Perth at Lat.(S): -32.0, Long.(E): 115.9, 20 m above sea level; and Mandurah at Lat.(S): -32.5, Long.(E): 115.7 (all decimal degrees), 22 m above sea level. The transformed data were sourced from the RETScreen's (version 4) climate database, incorporating the improved NASA Surface Meteorology and Solar Energy Dataset. The monthly average and annual average clearness index and daily radiation at both locations are shown in Fig. 2 and 3 (HOMER 'screenshots') using degrees, minutes, seconds. The monthly average and annual average temperatures of both locations are shown in Fig. 4 and 5.



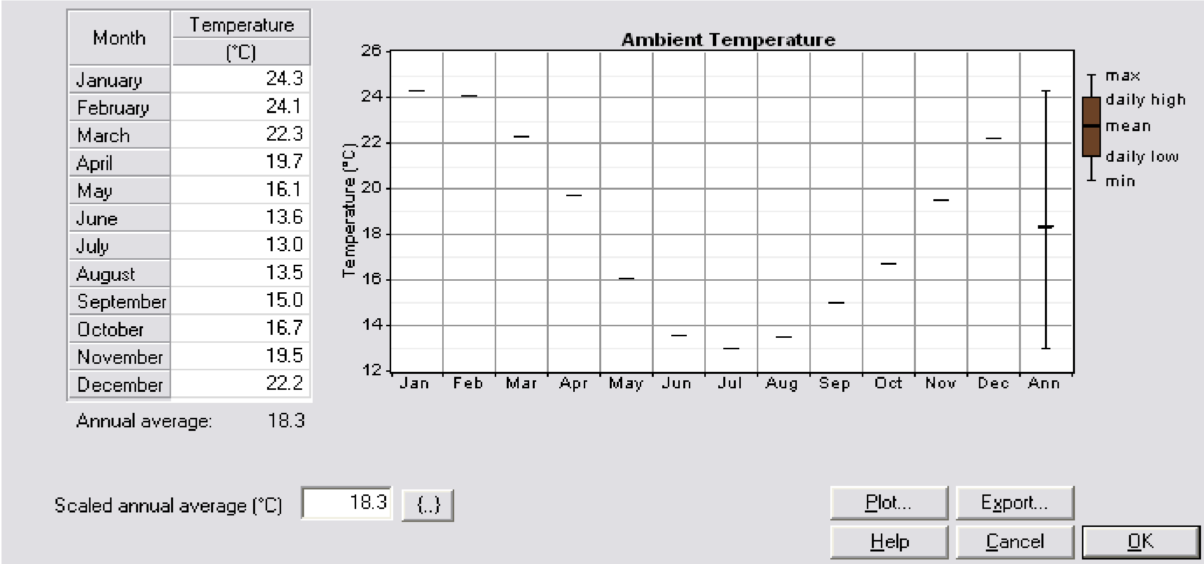
Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.706	8.450
February	0.687	7.530
March	0.648	6.020
April	0.601	4.380
May	0.560	3.160
June	0.546	2.660
July	0.551	2.870
August	0.572	3.750
September	0.602	5.100
October	0.634	6.560
November	0.664	7.750
December	0.696	8.500
Average:	0.638	5.551

Fig. 2: Perth solar resource simulation input data.



Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.707	8.470
February	0.691	7.560
March	0.651	6.020
April	0.602	4.350
May	0.550	3.060
June	0.532	2.550
July	0.535	2.740
August	0.561	3.640
September	0.593	4.990
October	0.632	6.520
November	0.663	7.730
December	0.687	8.400
Average:	0.635	5.492

Fig. 3: Mandurah solar resource simulation input data.

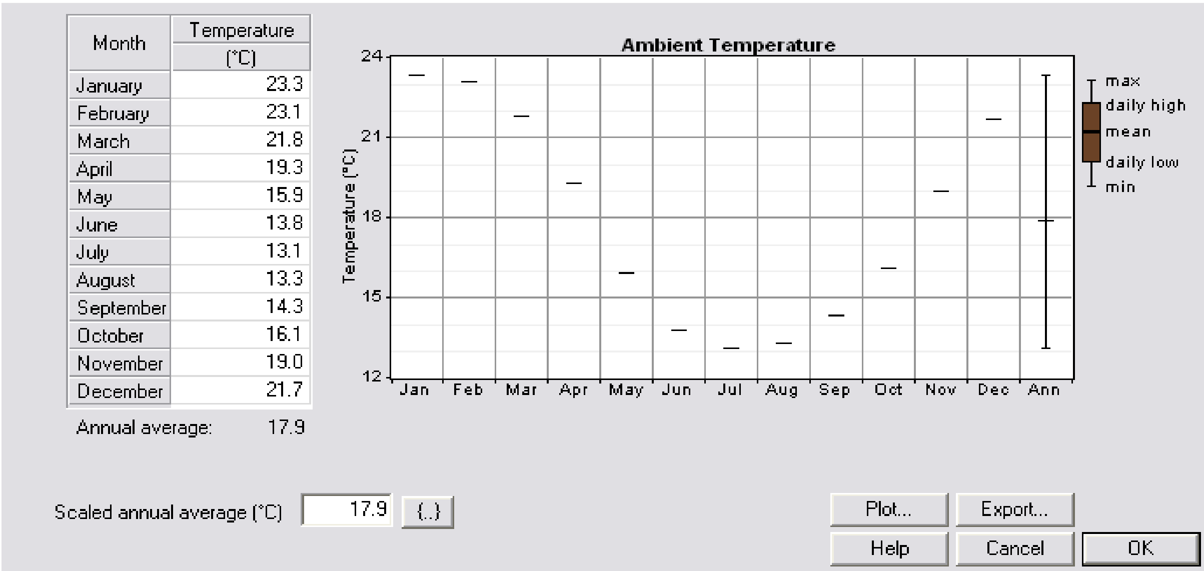


Month	Temperature (°C)
January	24.3
February	24.1
March	22.3
April	19.7
May	16.1
June	13.6
July	13.0
August	13.5
September	15.0
October	16.7
November	19.5
December	22.2

Annual average: 18.3

Scaled annual average (°C) 18.3

Fig. 4: Perth ambient air temperature simulation input data.



Month	Temperature (°C)
January	23.3
February	23.1
March	21.8
April	19.3
May	15.9
June	13.8
July	13.1
August	13.3
September	14.3
October	16.1
November	19.0
December	21.7

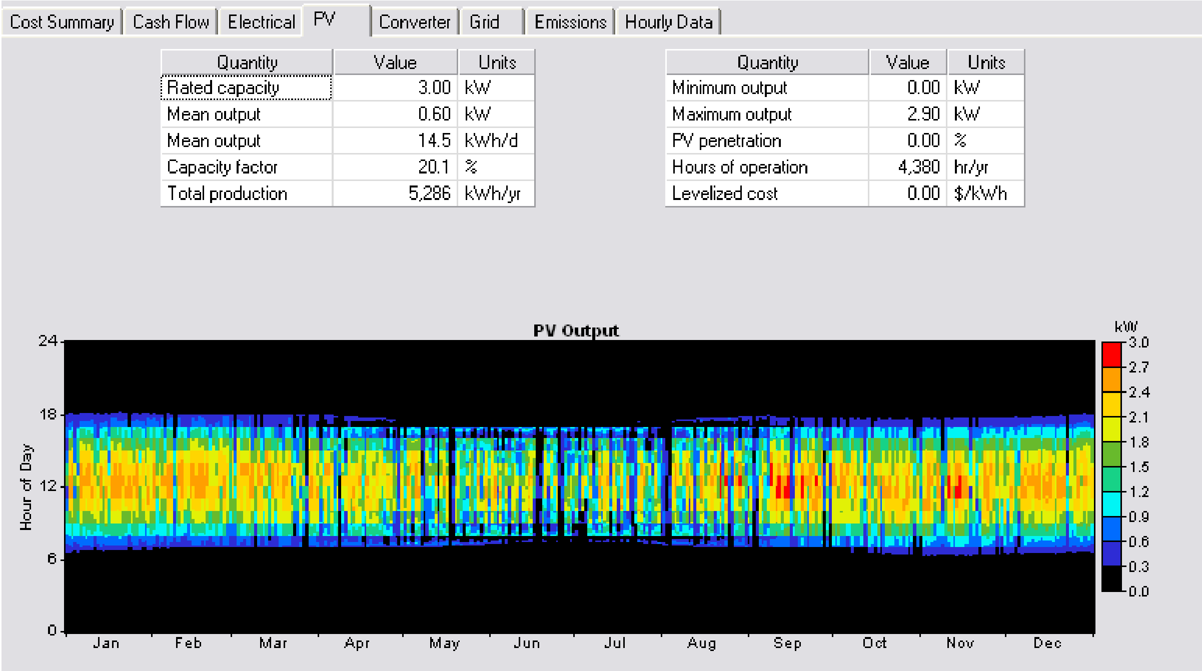
Annual average: 17.9

Scaled annual average (°C) 17.9

Fig. 5: Mandurah ambient air temperature simulation input data.

3. System Simulation Results

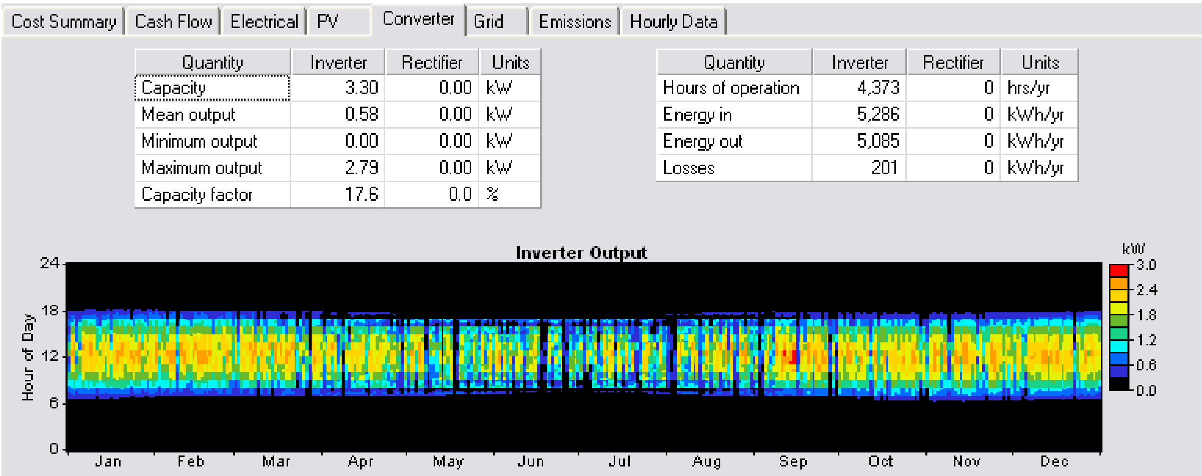
Fig. 6 shows example PV array simulation results for each 10 minute interval in an average year at the Perth location. The selected example array orientation is 32 degrees above horizontal and an azimuth of 180 degrees West of South (due North). The 'total production' of the array represents the total annual simulated kWh generated by the PV component at this location and orientation over one year. Fig. 7 shows the simulated inverter performance for the same system and orientation example in Perth. The 'energy in' represents the DC electricity generated by the PV array, and the 'energy out' is the net AC electricity output of the inverter (and thus the PV-inverter system). The inverter output (kW) is shown graphically for each simulated 10 minute interval.



Quantity	Value	Units
Rated capacity	3.00	kW
Mean output	0.60	kW
Mean output	14.5	kWh/d
Capacity factor	20.1	%
Total production	5,286	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	2.90	kW
PV penetration	0.00	%
Hours of operation	4,380	hr/yr
Levelized cost	0.00	$/kWh

Fig. 6: Example 10 minute interval PV array simulated generation data for Perth.



Quantity	Inverter	Rectifier	Units
Capacity	3.30	0.00	kW
Mean output	0.58	0.00	kW
Minimum output	0.00	0.00	kW
Maximum output	2.79	0.00	kW
Capacity factor	17.6	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	4,373	0	hrs/yr
Energy in	5,286	0	kWh/yr
Energy out	5,085	0	kWh/yr
Losses	201	0	kWh/yr

Fig. 7: Example 10 minute interval inverter simulated output data for Perth.

The results of the 338 separate system simulations collated for this report represents the output of the inverter, or 'energy out'. The systems simulated annual PV-inverter system output (in $kWh/kW_p/year$) for each of the 169 PV array orientations for Perth are shown in Fig. 8, and the respective simulations for Mandurah in Fig. 9. Colour was arbitrarily introduced to show variability of the total system output. All system simulations are shown on a kWh/kW_p basis for both Perth and Mandurah in Fig. 10 and 11, respectively. This enables decisionmakers to quickly estimate the performance of a PV arrays of any size, orientation, and angle in Perth and Mandurah using the specified technology.

PV array angle (degrees relative to horizontal)

Azimuth (degrees W of S)

		17	19.5	22	24.5	27	29.5	32	34.5	37	39.5	42	44.5	47
W	90	4,606	4,571	4,533	4,491	4,446	4,398	4,348	4,295	4,241	4,184	4,125	4,065	4,003
	105	4,726	4,707	4,684	4,657	4,625	4,590	4,552	4,509	4,464	4,416	4,364	4,310	4,254
	120	4,835	4,830	4,819	4,804	4,783	4,759	4,730	4,696	4,658	4,616	4,571	4,521	4,467
	135	4,927	4,933	4,933	4,927	4,916	4,899	4,877	4,849	4,816	4,778	4,735	4,688	4,636
	150	4,996	5,010	5,018	5,019	5,014	5,003	4,986	4,963	4,934	4,899	4,858	4,812	4,760
	165	5,042	5,061	5,074	5,080	5,080	5,072	5,058	5,038	5,010	4,977	4,937	4,891	4,838
	180	5,060	5,082	5,097	**5,105**	**5,106**	5,100	5,087	5,068	5,041	5,009	4,969	4,924	4,872
	195	5,051	5,072	5,085	5,092	5,092	5,085	5,072	5,052	5,027	4,994	4,955	4,910	4,859
	210	5,015	5,031	5,041	5,044	5,042	5,033	5,018	4,996	4,969	4,935	4,896	4,851	4,800
	225	4,952	4,960	4,962	4,959	4,950	4,936	4,916	4,891	4,861	4,825	4,785	4,740	4,689
	240	4,864	4,862	4,855	4,843	4,826	4,803	4,777	4,746	4,710	4,670	4,625	4,577	4,526
	255	4,758	4,743	4,723	4,698	4,670	4,637	4,601	4,562	4,519	4,474	4,425	4,373	4,318
E	270	4,639	4,607	4,572	4,533	4,491	4,446	4,399	4,349	4,296	4,242	4,185	4,127	4,068

Fig. 8: Simulated 3 kW_p system output (kWh/year) for Perth at selected orientations.

PV array angle (degrees relative to horizontal)

Azimuth (degrees W of S)

		17	19.5	22	24.5	27	29.5	32	34.5	37	39.5	42	44.5	47
W	90	4,567	4,533	4,495	4,453	4,409	4,362	4,312	4,260	4,206	4,150	4,092	4,032	3,971
	105	4,686	4,668	4,645	4,618	4,587	4,553	4,514	4,473	4,428	4,380	4,330	4,276	4,221
	120	4,795	4,790	4,779	4,764	4,744	4,720	4,691	4,658	4,621	4,580	4,535	4,485	4,432
	135	4,886	4,892	4,892	4,887	4,876	4,859	4,838	4,810	4,778	4,740	4,698	4,651	4,600
	150	4,955	4,969	4,977	4,979	4,974	4,963	4,946	4,923	4,895	4,861	4,821	4,775	4,724
	165	5,001	5,020	5,033	5,039	5,039	5,039	5,018	4,998	4,971	4,938	4,898	4,853	4,801
	180	5,019	5,041	5,056	**5,064**	**5,065**	5,059	5,047	5,028	5,002	4,970	4,931	4,886	4,835
	195	5,010	5,031	5,045	5,051	5,052	5,046	5,033	5,014	4,988	4,956	4,918	4,874	4,823
	210	4,974	4,991	5,001	5,005	5,002	4,994	4,980	4,959	4,932	4,899	4,860	4,816	4,766
	225	4,912	4,921	4,924	4,921	4,913	4,899	4,879	4,855	4,825	4,791	4,751	4,706	4,657
	240	4,826	4,824	4,817	4,806	4,789	4,768	4,741	4,711	4,676	4,636	4,593	4,546	4,495
	255	4,721	4,705	4,686	4,662	4,634	4,602	4,567	4,529	4,487	4,442	4,394	4,342	4,289
E	270	4,602	4,571	4,536	4,499	4,457	4,413	4,366	4,317	4,265	4,212	4,156	4,099	4,040

Fig. 9: Simulated 3 kW_p system output (kWh/year) for Mandurah at selected orientations.

PV array angle (degrees relative to horizontal)

Azimuth (degrees W of S)		17	19.5	22	24.5	27	29.5	32	34.5	37	39.5	42	44.5	47
W	90	1,535	1,524	1,511	1,497	1,482	1,466	1,449	1,432	1,414	1,395	1,375	1,355	1,334
	105	1,575	1,569	1,561	1,552	1,542	1,530	1,517	1,503	1,488	1,472	1,455	1,437	1,418
	120	1,612	1,610	1,606	1,601	1,594	1,586	1,577	1,565	1,553	1,539	1,524	1,507	1,489
	135	1,642	1,644	1,644	1,642	1,639	1,633	1,626	1,616	1,605	1,593	1,578	1,563	1,545
	150	1,665	1,670	1,673	1,673	1,671	1,668	1,662	1,654	1,645	1,633	1,619	1,604	1,587
	165	1,681	1,687	1,691	1,693	1,693	1,691	1,686	1,679	1,670	1,659	1,646	1,630	1,613
	180	1,687	1,694	1,699	**1,702**	**1,702**	1,700	1,696	1,689	1,680	1,670	1,656	1,641	1,624
	195	1,684	1,691	1,695	1,697	1,697	1,695	1,691	1,684	1,676	1,665	1,652	1,637	1,620
	210	1,672	1,677	1,680	1,681	1,681	1,678	1,673	1,665	1,656	1,645	1,632	1,617	1,600
	225	1,651	1,653	1,654	1,653	1,650	1,645	1,639	1,630	1,620	1,608	1,595	1,580	1,563
	240	1,621	1,621	1,618	1,614	1,609	1,601	1,592	1,582	1,570	1,557	1,542	1,526	1,509
	255	1,586	1,581	1,574	1,566	1,557	1,546	1,534	1,521	1,506	1,491	1,475	1,458	1,439
E	270	1,546	1,536	1,524	1,511	1,497	1,482	1,466	1,450	1,432	1,414	1,395	1,376	1,356

Fig. 10: Simulated system output on a kWh/kW$_p$/year basis for Perth at selected orientations.

PV array angle (degrees relative to horizontal)

Azimuth (degrees W of S)		17	19.5	22	24.5	27	29.5	32	34.5	37	39.5	42	44.5	47
W	90	1,522	1,511	1,498	1,484	1,470	1,454	1,437	1,420	1,402	1,383	1,364	1,344	1,324
	105	1,562	1,556	1,548	1,539	1,529	1,518	1,505	1,491	1,476	1,460	1,443	1,425	1,407
	120	1,598	1,597	1,593	1,588	1,581	1,573	1,564	1,553	1,540	1,527	1,512	1,495	1,477
	135	1,629	1,631	1,631	1,629	1,625	1,620	1,613	1,603	1,593	1,580	1,566	1,550	1,533
	150	1,652	1,656	1,659	1,660	1,658	1,654	1,649	1,641	1,632	1,620	1,607	1,592	1,575
	165	1,667	1,673	1,678	1,680	1,680	1,680	1,673	1,666	1,657	1,646	1,633	1,618	1,600
	180	1,673	1,680	1,685	**1,688**	**1,688**	1,686	1,682	1,676	1,667	1,657	1,644	1,629	1,612
	195	1,670	1,677	1,682	1,684	1,684	1,682	1,678	1,671	1,663	1,652	1,639	1,625	1,608
	210	1,658	1,664	1,667	1,668	1,667	1,665	1,660	1,653	1,644	1,633	1,620	1,605	1,589
	225	1,637	1,640	1,641	1,640	1,638	1,633	1,626	1,618	1,608	1,597	1,584	1,569	1,552
	240	1,609	1,608	1,606	1,602	1,596	1,589	1,580	1,570	1,559	1,545	1,531	1,515	1,498
	255	1,574	1,568	1,562	1,554	1,545	1,534	1,522	1,510	1,496	1,481	1,465	1,447	1,430
E	270	1,534	1,524	1,512	1,500	1,486	1,471	1,455	1,439	1,422	1,404	1,385	1,366	1,347

Fig. 11: Mandurah's simulated system outputs on a kWh/kW$_p$/year basis at selected orientations.

Based on the input data and assumptions, the resulting simulations suggest the optimum angle of orientation at both locations of Perth and Mandurah are roughly between 24.5 and 27 degrees relative to horizontal, and an azimuth of 180 (W of S), facing North. The simulations show a noticeable, yet small decline in the number of system orientations in Mandurah which achieve 5,065 kWh/year when compared to Perth (5106 kWh/year). According to the simulations, the highest solar resource PV array orientation for both locations is positioned 27 degrees from the horizontal, with an azimuth of 180 (W of S) in Perth. The difference between the highest system performance in Perth and Mandurah was a simulated 41 kWh, a relatively small difference over the year. The difference in system outputs between the orientations between 19.5 and 32 degrees and azimuths of 165 to 195, are relatively small in terms of the total annual output. However, outside of these preferable orientations and azimuths, there are clear reductions in simulated total annual output. When considering the uncertainty inherent in the simulations, an unshaded array orientated anywhere between these preferable orientations will likely provide a very high level of annually averaged production for a fixed array.

The simulations suggest a slight additional benefit of installing PV-inverter systems in Perth (or any lower latitudes in the Northern regions of metropolitan Perth) relative to Mandurah, due to higher system performance. In terms of any additional losses (such as shading) that may occur on each individual site, this can be managed by selecting PV array orientations and roofsite locations with relatively higher solar access. As the actual shading at any one site varies from time of day and seasonally, this will impact various PV array orientation performance in a different manner and to a varied extent. The unique characteristics of each shading types are outside the scope of this analysis. Nonetheless, this data enables decisionmakers to compare various PV array orientations and locations around the Perth metropolitan region, and quickly estimate their relative technical performance with some level of certainty.

5. Analysis Risk Summary

The authors believe the primary technical risk in this analysis relates to the assumption of zero shading of the PV array, and the use of averaged monthly temperature data in simulations. Such an analysis was outside the work scope for the system, yet to some extent was catered for in the very conservative PV array derating of 85%, which may underestimate actual system performance. This report was developed to assist the selection of suitable array orientations and angles for decisionmakers, and the relative margins of uncertainty in terms of potentially significant impediments to the optimal capture of direct solar irradiance at various times of the day and year under a number of conditions.

6. References

1. HOMER Energy LLC. 2010. HOMER Version 2.68 beta. www.nrel.gov/homer.

Author Bios

Dr. Mark P McHenry researches in the School of Engineering and Energy, Murdoch University. Mark has published several peer-reviewed journal articles and book chapters on renewable energy technology, carbon biosequestration, renewable resources, bioenergy conversion technologies, energy sector restructuring, rural development, and agricultural mitigation and adaptation to climate change.

Dr. Trevor Pryor has decades of experience teaching and researching renewable energy system technology and simulation software at various institutions, including the School of Engineering and Energy, at Murdoch University. His research interests include system simulation, analysis, energy management, system monitoring, and testing of remote area power supply systems and components.